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Cruise report on the simultaneous observation of the Japan Sea in October 1969

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Maizuru Marine Observatory

(Received September 30, 1971)

Abstract: A simultaneous observation in the Japan Sea by the five observation ships was carried out in October 1969.

Movements of the surface water, of the deep water (500 m depth), and of the bottom water (1200 m depth) were considered, and a larger velocity (1.3 miles/day) than those which had been reported on the current of the bottom water in the Japan Basin was found.

Studies on the vertical structure of the water masses in the Japan Sea were made. Two maximum layers (at 30 m and 200 m depth) and two minimum layers (at 75 m and 1000 m depth) of the dissolved oxygen content were found in the Tsushima Warm Current area.

A simultaneous observation for the study on the movement of the sea water and on the horizontal and vertical structure of the water masses in the Japan Sea (Fig. 1) was carried out in October 1969, by the five vessels of the Japan Meteorological Agency (JMA) listed on Table 1.

1. Sampling

Eighty-five stations for hydrographic casts were made as a rule at every one degree in both latitude and longitude. At the Tsushima Straits and near the entrance of the Tsugaru Straits the stations were settled at shorter intervals. Sampling depths were chosen at 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 800, 1000, 1200, 1500, 2000, 2500, 3000, 3500 m, and near bottom.

Observations with GEK and BT were made at each hydrographic station and at the half way between one station and another. Soundings with the echo sounder and surface salinity with self-recording salinometer were obtained continuously along the cruising course of each vessel. Maritime meteorological observations were done every three hours.

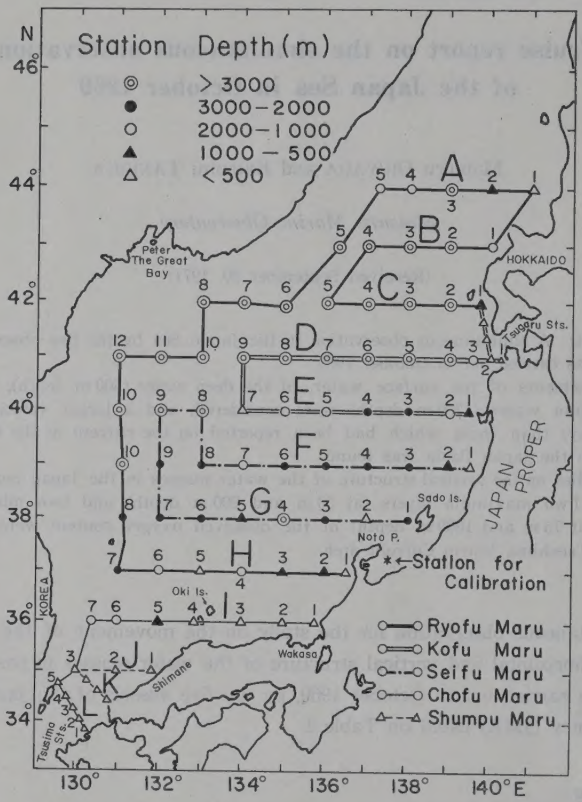

Fig. 1. Location of stations occupied by the five vessels for the simultaneous observation in the Japan Sea in October 1969.

Chemical elements determined on board are salinity, dissolved oxygen, phosphate-P, and nitrate-N. Partial pressures of carbon dioxide in the atmosphere and in the surface water were determined only on board the Ryofu Maru.

The Norpac net (GG54, 0.33 mm mesh) was hauled vertically from the estimated depth of 150 m at every station for the standard sampling of zooplankton. For the study on the vertical distribution of zooplankton, samplings with the closing net were made from five layers (0–250 m, 250–500 m, 500–1000 m, 1000–2000 m and 2000–3000 m) at three stations occupied by Ryofu Maru. Surface water of 500 m*l* was

Table 1. Vessels and personnel participated in the simultaneous observation in the Japan Sea in October 1969.

Vessels	Ryofu Maru	Seifu Maru	Kofu Maru	Chofu Maru	Shumpu Maru
Gross tonage	1600	355	350	270	150
Observatory	Marine Division, JMA	Maizuru Marine Observatory, JMA	Hakodate Marine Observatory, JMA	Nagasaki Marine Observatory, JMA	Kobe Marine Observatory, JMA
Observation line	A, B, C, western stations of D-G, H	F, G, western stations of E	D, E	I, L	J, K
Period of observation	29 September–9 October	7–18 October	11–15 October	15–17 October	14–15 October
Captain	Shirakawa, K.	Yasuda, H.	Naka, C.	Matsuno, M.	Sasaki, S.
Scientists, Chief	Sawara, T.	Ohwada, M.	Hosoda, S.	Tsuchida, T.	Konaga, S.
	Akiyama, T.	Yasuoka, T.	Hata, K.	Asaoka, O.	Baba, N.
	Fujiwara, I.	Hashimoto, H.	Hayashi, H.	Hanzawa, Y.	Hori, K.
	Kawarada, Y.	Hayashi, K.	Karoji, K.	Maeda, Y.	Irie, K.
	Kimura, K.	Kishii, T.	Konya, T.	Masaki, N.	Kuroda, K.
	Kitou, M.	Nagasaka, K.	Kuronuma, S.	Matsuzaki, M.	Shuto, K.
	Sagi, T.	Ogawa, F.	Marui, S.	Morikawa, S.	Yakushijin, T.
	Sato, N.	Tanioka, K.	Terashima, I,	Nagata, M.	Yamamoto, K.
	Urashima, T.	Harami, K.	Wakaki, S.	Yamano, S.	
	Yoshimura, K.	Nishida, H.	Yamamoto, K.		
	Yura, T.	Sawada, Y.			
		Sekimoto, C.			

sampled at all stations for the quantitative determination of microplankton. Sample water was drawn from Nansen bottle at 12 depths in the upper 500 m at the stations on the B, E, and G line for the study on the vertical distribution of microplankton, and water samples for determination of chlorophyll and phaeophytin were taken from Nansen bottles at 10 depths in the upper 300 m at the stations on the A, B, C, G, and H line.

2. An outline of the results

(1) Movements of water

a) Surface currents

The stream lines of the Tsushima Warm Current in the north of 40°N are clearly estimated from the geopotential topography of the surface relative to 1000-decibar surface (Fig. 2). As SUDA and HIDAKA (1932) and SHIMOMURA and MIYATA (1957) reported, three branches of the Tsushima Warm Current are distingushed.

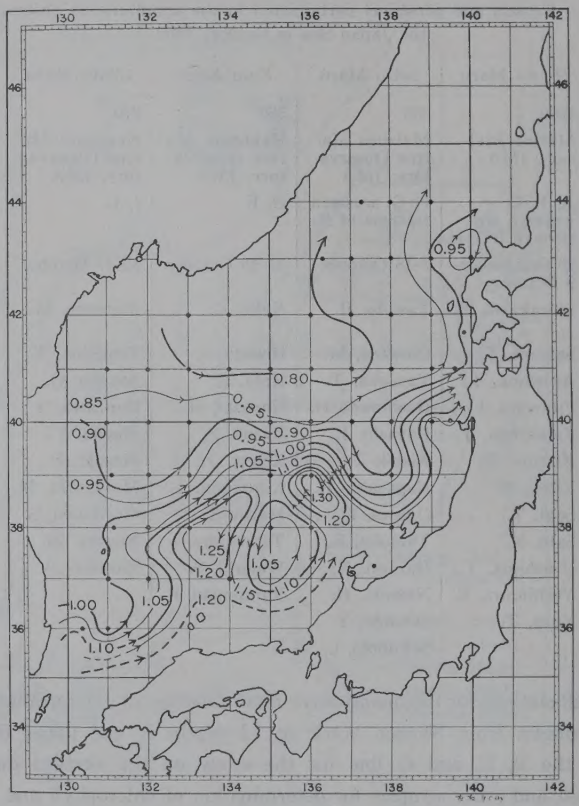

Fig. 2. Geopotential topography of the sea surface in dynamic meters referred to the 1000-decibar surface.

The first branch flows along the coast of Japan Proper. The second branch meanders around the Shimane Low Temperature Region (LTR), the High Temperature Region (HTR) at the north of the Oki Islands, the San'in-Wakasa LTR, Noto-NW HTR, and Sado LTR, in sequence, and flows toward the Tsugaru Straits. The third branch originating from the East Korean Warm Current (TANIOKA, 1968) meanders eastwards between 39° and 40°N and joins to the second branch at the north of Sado Island. Most part (ca. 70%) of the Tsushima Warm Current water runs away from the Tsugaru Straits, and the rest part flows northward along the

west coast of Hokkaido.

The current pattern of the Tsushima Warm Current in the south of 40°N measured with GEK (Fig. 3) corresponds well to that obtained by dynamical calcu-

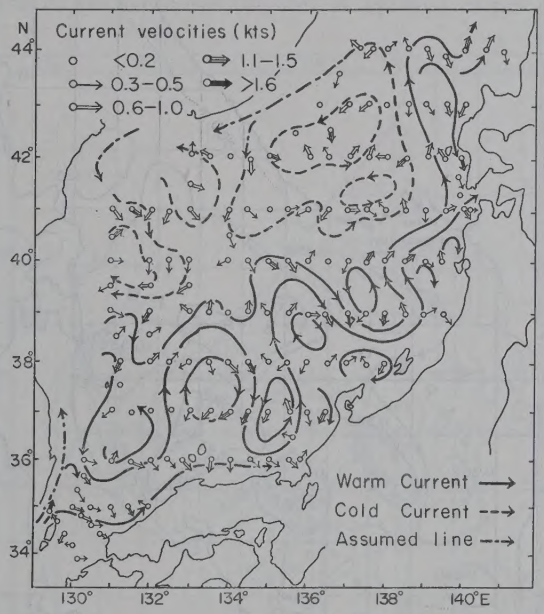

Fig. 3. Surface currents measured with GEK.

lation (Fig. 2). Furthermore the current pattern of the cold water area in the north of 40°N is also estimated fairly well from the results obtained by GEK. In the eastern part of the cold water area a cyclonic current of a relatively large scale is found, and an anticyclonic current exists in the western part of it. A small cyclonic eddy is observed between them. These current patterns correspond well with the distributions of temperature, salinity, dissolved oxygen, and nutrient salts in the surface water.

b) Movement of the deep water

SUDA and HIDAKA (1932) stated that the deep water lies below the second thermocline in the Sea of Japan, and UDA (1934) reported that the deep water occupies the depths from 500 to 1000 m.

Here 500 m level was chosen in order to investigate the current of the deep

water in the Japan Sea (Fig. 4). In the eastern part of the Japan Basin a cyclonic

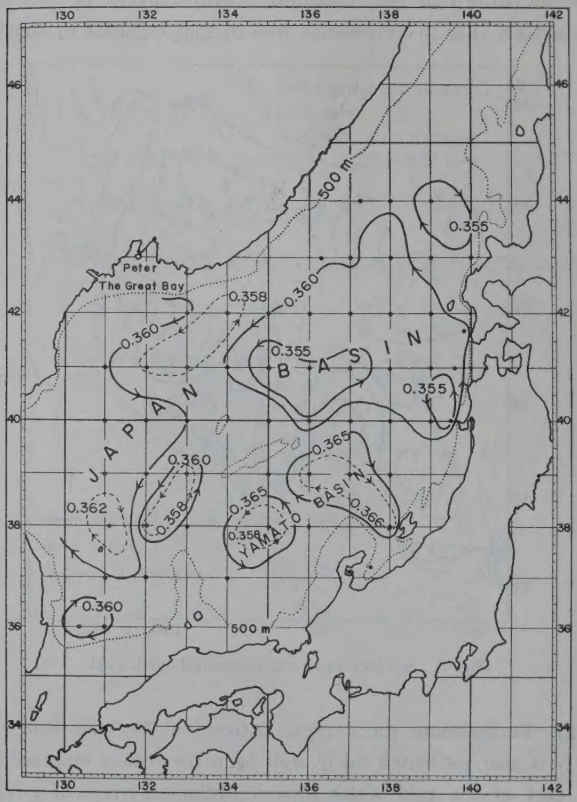

Fig. 4. Geopotential topography of the 500m depth in dynamic meters referred to the 1000-decibar surface.

current with the maximum velocity of 3 cm/sec is found. An anticyclonic current in the eastern part of the Yamato Basin and a cyclonic current in the western part of it are seen. There is a weak current which flows southward from the south of Peter the Great Bay to 37°N and turns to the right.

c) Movement of the bottom water

SUDA (1932) named the water mass below the minimum layer of temperature, salinity, and dissolved oxygen as the bottom water in the Japan Sea, and he de-

scribed that the bottom water creeps slowly along the basin of the Japan Sea in cyclonic direction with a velocity of about 0.1 mile per day.

In this report the current at 1200 m depth is calculated to see the motion of the bottom water in the Japan Sea (Fig. 5). A cyclonic current with a velocity

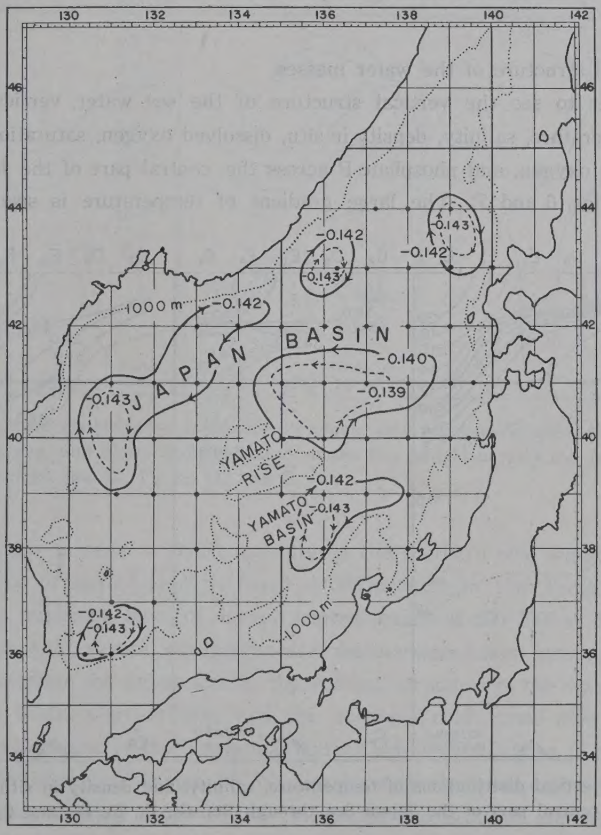

Fig. 5. Geopotential topography of the 1200m depth in dynamic meters referred to the 1000-decibar surface.

of 1.3 miles per day at the maximum is seen at the eastern part of the Japan Basin, and an anticyclonic current with the same velocity is found in the Yamato Basin. Anticyclonic currents with velocities of about 1.2 miles per day exist at

the western side and at the southwestern part of the Japan Basin. It is not clear, however, whether these currents exist independently or they are connected with each other into a large scale cyclonic current in the Japan Basin as SUDA (1932) stated. Anyhow it may be true that we can find a larger velocity than those which have been reported hitherto on the current of the bottom water in the Japan Basin.

(2) Vertical structure of the water masses

In order to see the vertical structure of the sea water, vertical sections of water temperature, salinity, density in situ, dissolved oxygen, saturation percentage of dissolved oxygen, and phosphate-P across the central part of the Japan Sea are shown in Figs. 6 and 7. The large gradient of temperature is seen at 20–50 m

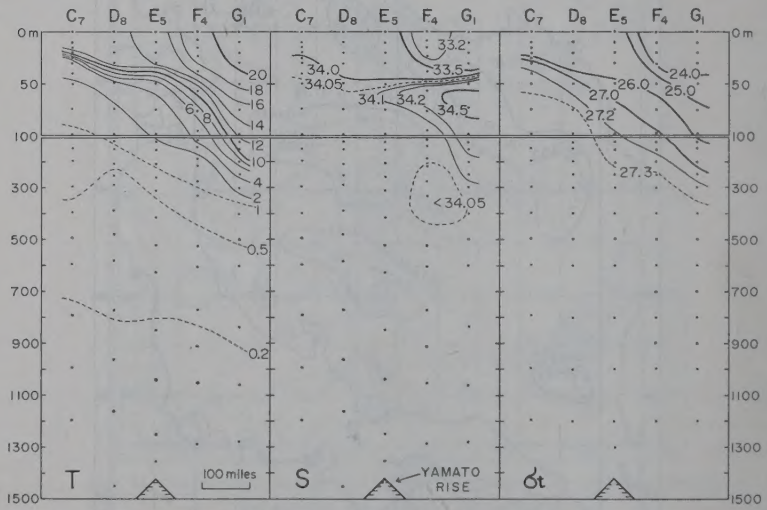

Fig. 6. Vertical distributions of temperature, salinity, and density in situ across the central part of the Japan Sea through Sts. G_1, F_4, E_5, D_8, and C_7.

depth in the northern cold water, while in the Tsushima Warm Current it is found at about 200 m depth. The Kernel Water of the Tsushima Warm Current with higher salinity than 34.20‰ (SUDA, 1932; UDA, 1934) is seen at 50–200 m depth in the Tsushima Warm Current, but in the northern cold water such an apparent high saline water is not found. The maximum value (more than 7.5 ml/l) of the

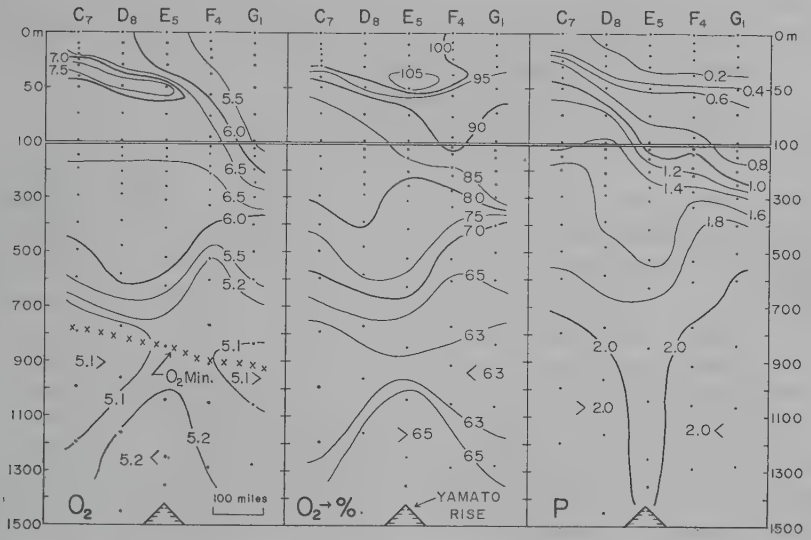

Fig. 7. Vertical distributions of dissolved oxygen, saturation percentage of dissolved oxygen, and phosphate-phosphorus across the central part of the Japan Sea through Sts. G_1, F_4, E_5, D_8, and C_7.

dissolved oxygen is seen at 30–50 m depths in the northern cold water, while the maximum value of mere 6.5 m*l*/*l* is found at 300 m depth in the Tsushima Warm Current. The minimum layer of oxygen content exists at 800–1000 m depths.

Mean values of several oceanographical factors were taken into consideration for the comparison of the differences in the vertical structure of the water between the Tsushima Warm Current area and the northern cold water area (Table 2). The water temperature in the Tsushima Warm Current (TWC) area is higher than that in the Northern Cold Water (NCW) area between the surface and 400 m depth, while it becomes contrary below 500 m. Minimum temperatures are seen between 1000 m and 1200 m depth in both areas. The maximum values of salinity are found at 100 m depth in the TWC area and at 75 m depth in the NCW area. The minimum values are seen at 300 m depth in both areas. The density in situ increases in accordance with increasing of depth down to 1000 m, and the constant value is seen from 1200 m to the bottom in both areas. Two maxima and two minima of dissolved oxygen content are found in the TWC area. The upper maximum is

Table 2. Mean values of temperature, salinity, density in situ, dissolved oxygen, saturation percentage of dissolved oxygen, and phosphate-phosphorus in the Tsushima Warm Current (TWC) area (south of 39°N), and those in the Northern Cold Water (NCW) area (north of 40°N). Numerals with solid under-line denote the maximum values, and those with broken under-line indicate the minimum values.

Elements	Temperature (°C)		Salinity (‰)		Density in situ		Dissolved Oxygen (ml/l)		Saturation percentage of oxygen		Pohsphate-P (μg-atoms/l)	
Water mass	TWC	NCW	TWC	NCW	TWC	NCW	TWC	NWC	TWC	NCW	TWC	NCW
Depth (m)												
0	20.5	16.8	32.970	33.701	23.11	24.60	5.21	5.84	97	103	0.15	0.21
10	20.45	15.32	32.970	33.727	23.12	24.94	5.21	5.87	97	101	0.16	0.21
20	20.36	15.09	33.093	33.730	23.25	24.99	5.21	5.91	97	101	0.18	0.23
30	19.88	13.14	33.269	33.842	23.70	25.48	5.23	6.41	96	106	0.23	0.32
50	17.05	5.59	33.991	34.070	24.77	26.90	5.01	7.09	89	100	0.51	0.73
75	14.25	2.76	34.094	34.093	25.45	27.20	4.77	6.62	80	88	0.73	1.07
100	11.69	1.77	34.268	34.088	26.11	27.28	5.06	6.53	81	85	0.85	1.15
125	8.17	1.51	34.216	34.084	26.65	27.29	5.66	6.54	85	84	0.94	1.20
150	5.49	1.31	34.155	34.081	26.97	27.30	5.88	6.54	83	84	1.10	1.31
200	2.69	1.00	34.076	34.074	27.20	27.30	6.06	6.43	80	82	1.33	1.44
250	1.60	0.81	34.053	34.070	27.26	27.33	5.83	6.41	75	81	1.55	1.46
300	1.01	0.67	34.047	34.068	27.30	27.34	5.74	6.37	73	80	1.72	1.53
400	0.54	0.51	34.049	34.068	27.33	27.35	5.49	6.20	68	78	1.88	1.61
500	0.38	0.42	34.052	34.068	27.33	27.35	5.31	6.05	66	76	1.95	1.72
600	0.28	0.34	34.054	34.069	27.34	27.36	5.17	5.79	64	72	2.05	1.77
800	0.18	0.21	34.059	34.068	27.35	27.36	5.07	5.26	63	63	2.12	2.00
1000	0.14	0.15	34.062	34.070	27.35	27.36	5.05	5.07	62	63	2.14	2.04
1200	0.14	0.15	34.065	34.072	27.36	27.36	5.12	5.13	63	64	2.13	2.04
1500	0.16	0.17	34.068	34.073	27.36	27.36	5.18	5.20	64	64	2.13	2.00
2000	0.17	0.17	34.067	34.074	27.36	27.36	5.25	5.31	65	66	2.15	1.99
2500	0.20	0.20	34.066	34.076	27.36	27.36	5.29	5.34	66	66	2.16	1.96
3000	0.22	0.24	34.065	34.076	27.36	27.36	5.24	5.37	65	66	2.24	1.96
3500		0.28		34.077		27.36		5.34		66		1.90

thought to be brought by photosynthetic activities of phytoplankton, and the depth of the lower maximum corresponds to the boundary between the Kernel Water of the TWC and the Japan Sea Proper Water (UDA, 1934). The upper minimum means the center of the Kernel Water of the TWC, and the lower minimum layer of the TWC area corresponds with that of the NCW area. In the NCW slightly

larger values of phosphate-P than those in the TWC are found from the surface to 200 m depth, while they become contrary below 250 m. The maximum content of phosphate-P in the NCW is at 1000 m, from where the content decreases toward the bottom. The content of phosphate-P in the TWC increases from the surface to the 1000 m depth where it reaches the first maximum, and then it decreases downward to 1500 m and increases again toward the bottom where the second maximum is found.

It may be considered significant to study the relation between the minimum layer of temperature and oxygen and the maximum layer of phosphate-P, all of them exist at 1000 m depth.

3. Data report

The final data report of this survey will be seen in "The Results of Marine Meteorological and Oceanographical Observations, No. 46" published by the Japan Meteorological Agency. The distribution of nitrate nitrogen based on this data was already reported by SAGI (1970). The vertical distributions of microplankton, chlorophyll-a, and phaeopigment are being reported by OHWADA (1971, a and b). The detailed studies of other data taken for this survey will be also published on the coming issue of the "Oceanographical Magazine".

Acknowledgement

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1969年10月日本海一斉観測報告

大和田　守, 谷岡克巳

(舞鶴海洋気象台)

日本海の水の流動および水平・垂直的構造を追求するために，1969年10月気象庁所属の5隻の観測船により日本海の共同一斉観測を行なった．観測点は対馬海峡から44°Nに亘り緯経度一度ごとに配置し，観測層は海面から海底までとし，3500 m 以上の深さの所では24層に達した．

表面，500 m および 1200 m 深の流れについて考究したが，底層水では従来報告されていた流速（0.1 mile/day）よりもかなり速い速度（最大 1.3 miles day）の左旋流があることが判明した．

海水の垂直構造を見るために，各成分の日本海中央部を横切る断面分布，および暖流寒流別の各成分の平均値をとってみた．その結果は従来の説と大差はないが，暖流域の溶存酸素量の鉛直分布には2つの極大値と2つの極小値のあることを指摘した．

1000 m 深は水温および溶存酸素量の極小層，燐酸塩の極大層に相当するが，これらの関係について更に考究を加えることは，日本海の水の鉛直的循環を考える場合有要な鍵となるであろう．

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On the PCM-FS-FM tide telemetering system for warning of tsunamis and stormsurges

Mitsuo NAKAYAMA

Japan Meteorological Agency

(Received September 30, 1971)

Abstract: The system of PCM-FS-FM tide telemeter is designed, developed by the Japan Meteorological Agency and now used at 18 stations as shown in Fig. 1 in order to watch unusual sea level changes, such as tsunamis and stormsurges, and warn of them effectively and quickly.

In this system, tidal data measured with a float-type gauge are changed into digital signals by the A/D convertor of encoding disk and double brushes and transmitted in FS-FM mode repeatedly to distant manned stations. After receiving them, the codes are checked and only the correct data are recorded on the recording paper in analogue form.

As the errors of transmission and due to drift can be eliminated, the system has the precision of $\pm 0.3\%$.

1. Introduction

The Japan Meteorological Agency has been observing sea level changes at 53 stations along the coast of the islands of Japan with Fuess tide gauge. Usually recording papers are taken off every ten days, and the records are smoothed, read and processed statistically, which are very useful and valuable both for public services and scientific purposes. However, in order to watch unusual sea level changes such as tsunamis and stormsurges, it is necessary to send the values of sea level to manned weather stations on a real time basis. For this purpose telemetering systems of tidal data have been designed and developed. It started with telemetering the data measured with a pressure type tide gauge in analogue form (TERADA, et al, 1962) and the system was very useful but the values of sea level obtained from the system are not so accurate as to fit the recent public demands because of changeable sensitivity of the sensor and the decrease of precision, when it is operated for a long time. In order to get the values in the same accuracy for a long time, the rotation of pulley of a float-type tide gauge is designed to be changed into degital values with encoding disk. In this new system, the digitized tidal records are transmitted through the radio channel of 400MHz, received at distant weather stations and recorded in analogue form on the paper. For the

Fig. 1. Tidal stations where the telemetering system is installed; ● (belonging to the Japan Meteorological Agency) and ■ (to other agencies), where is planned to; ⊗ and ⊠, and, where is not installed; ○.

List of the stations

1. Wakkanai	2. Abashiri	3. Hanasaki	4. Kushiro
5. Hakodate	6. Iwasaki	7. Hachinohe	8. Miyako
9. Ofunato	10. Ayukawa	11. Onahama	12. Choshi
13. Tokyo	14. Mera	15. Okada	16. Uchiura
17. Shimizu	18. Toyama	19. Omaezaki	20. Maisaka
21. Katanohara	22. Handa	23. Nagoya	24. Toba
25. Owase	26. Uragami	27. Kushimoto	28. Shirahama
29. Wakayama	30. Tan'nowa	31. Osaka	32. Maizuru
33. Kobe	34. Sumoto	35. Himeji	36. Komatsushima
37. Murotomisaki	38. Uno	39. Takamatsu	40. Kochi
41. Saigo	42. Sakai	43. Matsuyama	44. Tosashimizu
45. Uwajima	46. Tonoura	47. Hofu	48. Shimonoseki
49. Aburatsu	50. Omuta	51. Ezaki	52. Misumi
53. Kagoshima	54. Oura	55. Kuchinotsu	56. Makurazaki
57. Nagasaki	58. Fukue	59. Yatsushiro	60. Hachijo

purpose of avoiding the transmission errors a Pulse Code Modulation-Frequency Shift-Frequency Modulation (PCM-FS-FM) system in digital cyclic pattern is used

and it makes us possible to get the desired precision of ±0.3%, ±3cm per 10m and good stability for a long time.

2. Explanation of the system

The telemetering system is designed so as to be operated reliably and stably for a long time, maintained well and handled easily.

2.1 Sensor

A float-type tide gauge is more convenient from the reason why it is now used and maintained in good condition at the tidal stations of the Japan Meteorological Agency, so we decided to use it as the sensor for this system.

2.2 A/D and D/A convertors

In this system an A/D convertor which consists of double brushes and an encoding disk is used. With this the rotating angles of a pulley of tide gauge are changed into digital values within the accuracy of ±1cm. The shortcoming of this convertor is that it contains a part of mechanical contact. But this would be overcome by replacing comparably cheap brushes and encoding disks at short intervals.

As a D/A convertor used at receiving station, an all transistor convertor of ladder-type is used. The convertor is not so accurate (±0.1%) as that of relay type (±0.02%), but much more reliable for long time use because it contains no mechanical parts.

2.3 transmission system

A PCM-FS-FM cyclic digital system is chosen, in which errors due to drift are very small and transmission errors can be deduced to almost zero by suitable checking. By this the precision of the whole system of ±0.3%, ±3cm per 10m, is obtained, as mentioned before, which is smaller than that of FM-FM analogue system (±0.6%).

Pulses of equal duration (no return to zero) are used, which makes the time neccessary for transmitting a frame of signals shorter than those of not equal duration. In this telemetering system, analogue values of sea levels are digitized, transmitted to distant manned weather stations, checked automatically, put back again to analogue values and recorded on the paper there, and it is necessary to transmit a series of signals as fast as possible, at least within the duration when

the sea level changes by the length of 1cm which corresponds to the least measureable value of the A/D convertor. The numerical value of sea level are usually three figures of binary coded decimal (see fig. 2). The time T neccessary for sending a value of sea level is counted as follows.

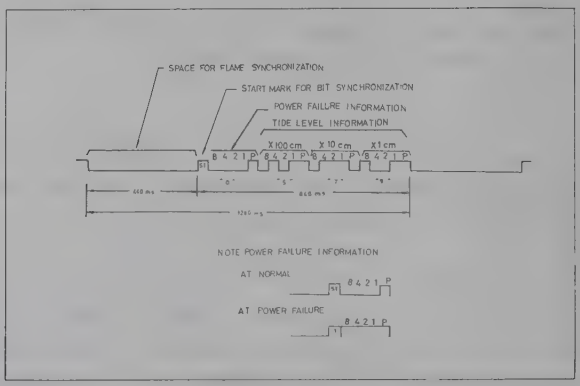

Fig. 2. Format of the transmitting code.

$$T = (11t + t + 5t + 3 \times 5t) = 32t\,,$$

where t is a pulse duration and equal to 40ms when the signals transmitted with the speed of 25 Bauds. Substituting $t = 40$ms, the time T becomes 1.28sec, which corresponds to the sea level change of 46cm per min. For example, the maximum change of sea level observed at the harbour of Hachinohe at the time of the last Chilean tsunami is about 5.9m in about 15min.

A received digital value in three figures of binary coded decimal form is checked for each figure whether the parity is not odd and the total is over, 9, and only the valid data are changed into analogue form. (see figs. 3 and 4)

2.5 Recorder

Received signals in digital form (0 to 999cm) are changed into electric potential in analogue form (0 to 2 volts) which is used as an input power of automatic balancing recorder with the accuracy of 0.3%. The recording ranges can be changed between two patterns, 0 to 10m and 0 to 5m in full scale, manually. Recorders now on the market have effective recording width of 250cm at widest,

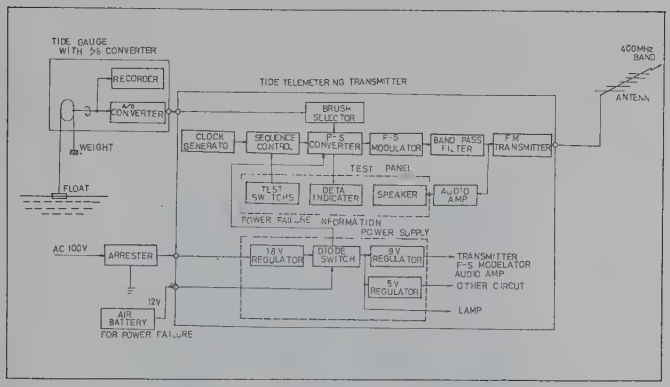

Fig. 3. Block diagram of the transmitting installation at tide station.

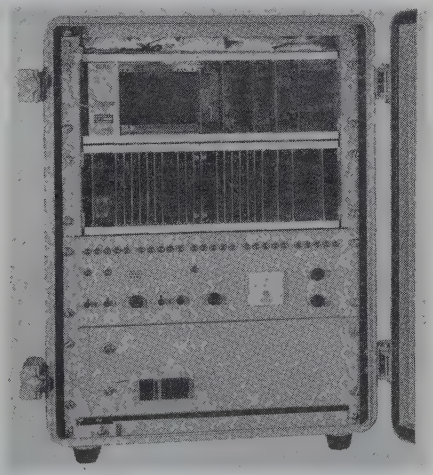

Fig. 4. Photograph of the transmitting installation.

while it is neccessary to get the same scales of record both in time and amplitude as those used in the tide gauge. For the purpose, an electronic circuit for shifting range is devised, which works only for the recording range of 0 to 5m in full scale. When sea level exceeds the value of 500cm, a flip-flop of the circuit is set, the value of 300 is subtracted from the content of the secondary memory and is transferred to the D/A convertor. A lamp is switched on while the range shift

circuit is working. When sea level is going down and reaches the value of 299cm, the flip-flop is reset and the subtraction is stopped. That is, the recording range is shifted between that of 0 to 5m and that of 3 to 8m with the hysterisis of 2m.

It is possible to set manually an arbitrary warning value in the memory in unit of 1cm. If sea level exceeds the value, the alarm indicator will be on.

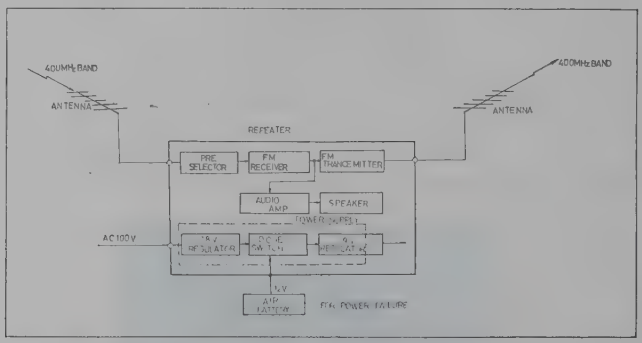

Fig. 5. Block diagram of the repeater at relaying station.

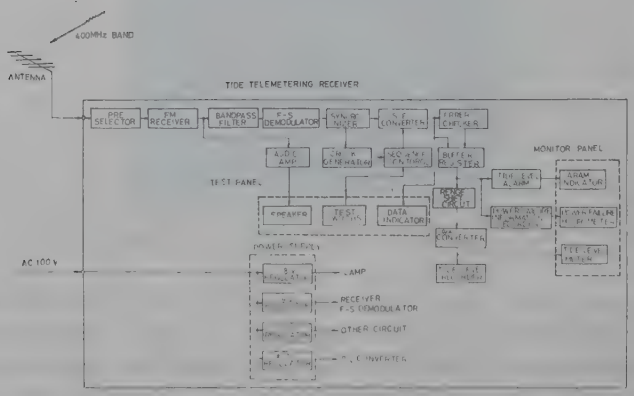

Fig. 6. Block diagram of the receiving installation at weather station.

2.5 Relaying station

In case the distance from tidal station to weather station is large or some obstacles are between them, relaying stations are placed. At the relaying station radio waves from tidal stations are automatically transmitted to weather station in a different frequency band. The working conditions at the relaying stations

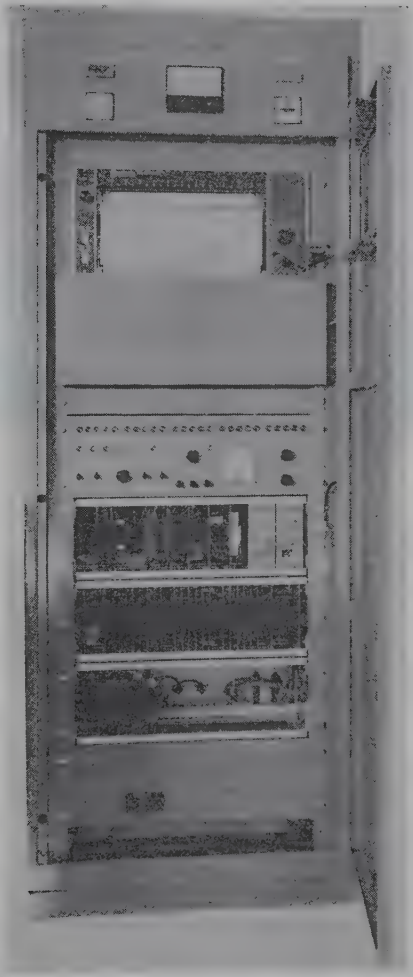

Fig. 7. Photograph of the receiving installation.

can be checked by the test pannel of the receiving installation at the weather station. (see figs. 5, 6 and 7)

3. Characteristics of the system

(1) sensor — Fuess tide gauge (see fig. 8)

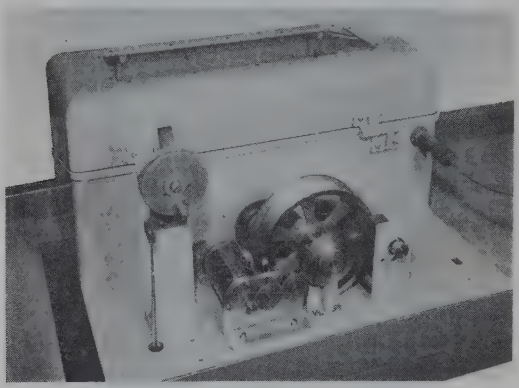

Fig. 8. Photograph of the tide gauge.

(2)	recording range		0 to 990cm
(3)	over all precision		±0.3% (±3cm per 10m)
(4)	transmission		PCM-FS-FM cyclic digital system
		channel	FM radio channel in 400MHz UHF zone
		power	0.3W (s/n 30 dB)
		speed	25 Bauds
		subcarrier	2635Hz
		frequency shift	±35Hz
(5)	signal	encoding	3 figures of binary coded decimal with a parity bit
		pulse	equal duration (NRZ)
		one frame	32 bits
		synchronization	frame synchronizing
		checking	odd parity and total check for each figure

	order	See fig. 2
(6) power	transmitting sta.	AC 100 ±10 volts of 50 or 60 Hz in single phase or DC 15 volts (90VA)
	receiving sta.	AC 100 ±10 volts of 50 or 60 Hz in single phase (100 VA)

4. Remarks and acknowledgement

This system is designed and developed as one of the modernizing plans for warning system of coastal disasters, and now woking at 18 tidal stations along the coast of Japan. With this it is sure to be able to warn of unusual changes of sea level quickly, precisely and effectively enough. Further, as the data are digitized and transmitted to the weather station every 1.28 sec, it is possible in near future to analyse and process them automatically by electronic computer.

At the end of this report the author wishes his thanks to Drs. Ichiro IMAI, Masami KOIZUMI, Masamori MIYAZAKI, Jotaro MASUZAWA, Hidetaka FUTI and Jiro SUGIURA, for their encouragements and useful advice, and also to Mr. Shinichi KURONUMA and Mr. Hayato IIDA for their kind helps.

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高潮・津波警戒用 PCM-FS-FM 潮位テレメータ

中　山　三　男

(気象庁・海洋気象部)

PCM-FS-FM 潮位テレメータは，高潮および津波警戒のための潮位隔測装置として気象庁が開発し展開しているものである．

本装置は，潮位を回転符号円板ダブルブラシ方式の A/D 変換器により ±1 cm の精度でディジタル化し，さらにパルスコード化した後，FS-FM 方式による無線回線で遠隔測定局（気象官署）に向けて繰返し伝送する．送受信点間の無線回線が悪い場合は，中継局を設ける．

これを受けた測定局では，復調した後符号検定を行ない，正しいデータのみ変換精度 ±0.1% の全電子式 D/A 変換器で直流電圧におき換え自動平衡記録計により潮位の連続記録を行なう．

以上の方式により本装置は，伝送誤差，漂動誤差を含まず総合誤差 ±0.3% の高確度を得ることができ，全国23カ所に設置する計画で既に18カ所において運用している．

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On the shape of the sea surface along the coast of islands of Japan

Hayato IIDA

Japan Meteorological Agency

(Received September 30, 1971)

Abstract: The shape of the sea surface along the coast of the islands of Japan is obtained from tidal data measured at about forty tidal stations of the Japan Meteorological Agency. As a reference level surface, the T.P. is chosen, which is the mean sea level measured at Reigan-jima, Tokyo from 1873 to 1876. The results of the leveling of the leveling network made public in 1969 by the Geographycal Survey Institute, are used in order to reduce the sea levels observed at tidal stations to those above the level surface.

Generally speaking, the values of sea levels along the coast of the Japan sea are, as expected, larger than those along the Pacific coast. In the Japan sea, to our surprise, the highest value of sea level is found at Iwasaki tide station on the northwestern coast of the Tohoku district in the downstream region of the Tsushima Warm Current. The lowest value is found along the coast of Tokaido.

The coastal shape of sea surface from tidal data matches very well to that obtained from the dynamic depth anomaly distribution, including the higher values observed along the west coast of the Tohoku district.

1. Introduction

Accompanied by a zonal wind system, the sea surface elevation of an ocean on a rotating sphere has maximal and minimal zones just east of the western boundary. In the zone the highest and lowest elevations of sea surface appear at the latitudes where the curl of wind stress is positive maximum and negative minimum, respectively (STOMMEL, 1948). When a simple functional form of the wind stress is taken as $-F\cos(\pi y/b)$, the sea level along the western boundary is expressed as follows,

$$h(y) = -A + B\cos(\pi y/b),$$

where y axis points northwards, b is the width of the ocean and A and B are the functions of the depth, gravity and friction of the ocean. The constant, A, is positive, so along the western boundary the averaged sea level is lower than that

over the whole ocean. From the equation, sea level is gradually going down northwards along the west coast with the highest at the southern end of the boundary.

In the Pacific Ocean, the highest zone is just south of the Japan Proper in the subtropical gyre (the Kuroshio system) and the lowest appears east of the Japan Proper and Hokkaido in the subarctic gyre (the Oyashio system). Sea levels along the coast of Japan are rather complicated because of the irregularity of the coastlines, and branching, meandering and contamination of the current systems. The most important current system affecting the coastal sea level is sure to be the Kuroshio itself and its branches. In this report the real shape of the sea surface along the coast will be investigated.

In order to know the shape of the sea surface it is neccessary to reduce tidal data observed at different tidal stations to the values above a reference level surface, such as T.P. Leveling of the networks of the first class bench marks for height must be done for short time compared with that of crustal movement or eaustatic changes and at the same time leveling between the standard mark of each tidal station and an appropriate first class bench mark (via the attached bench mark to the station) are neccessary in order to make the tidal data reduction significant. The leveling of the networks of first class bench marks has been done several times from the first of this century and has been made public by the

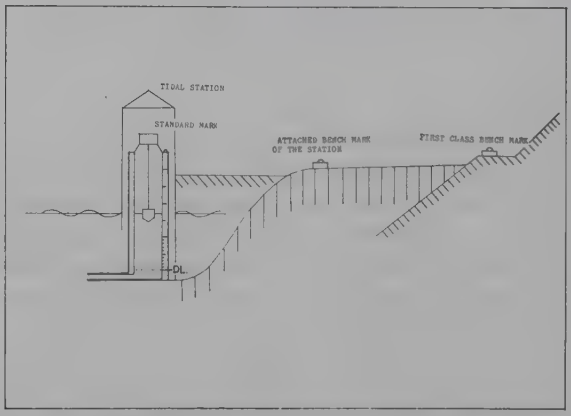

Fig. 1. Arrangement of bench marks for leveling (the first class bench mark is taken care for by the Geographical Survey Institute).

Geographical Survey Institute. Except the results made public in 1969, almost all the projects were done rather locally.

Leveling between the attached bench mark and a first class bench mark has been done every ten years for the stations on the relatively stable lands, every five years for those on the unstable places, and that between standard mark and attached bench mark has been done every year by the Japan Meteorological Agency (see fig. 1).

As the leveling project, the result of which were made public in 1969, was done for the comparatively short interval from 1963 to 1968, the mean sea levels for the interval and the monthly sea levels of the year 1965 are used for the following discussion (see figs. 2 and 3)

Fig. 2. Routes of the first class leveling by the Geographical Survey Institute from 1963 to 1968, the results of which were made public in 1969 as the adjusted values.

Fig. 3. Root mean square errors in mm for the adjusted values of first class bench marks made public in 1969, and tidal stations (○; those belonging to the Japan Meteorological Agency and ●; to other agencies).

2. Results of redution

Among the meteorological elements affecting the sea level changes, pressure does not make any baroclinic changes of oceanographic condition occur, so the effect must be eliminated from the sea level data for relatively long interval. The spatial variation of the atmospheric pressure for a month or much longer time is usually very small and gradually changing near Japan. The values are 1-2 mb in the warmer seasons and 5-8 mb in the colder seasons between the northernmost stations and those in the Kyushu district. The effect is very small and the correction is neglected in this report. In order to compare the values of different seasons, it is neccessary to add pressure correction, the method of which is not established yet. In this report quantitative comparison of sea level variations due to baroclinic causes in different seasons is abondoned.

Generally speaking, sea levels along the cost of the Japan sea are higher than those along the Pacific coast. The highest value appears, to my surprise, at the

north western coast of the Tohoku district, while the lowest is, as it is expected, along the coast of Tokaido where the trough of the Kuroshio is apt to be larger and cold water masses tend to be formed. (see figs. 4-5). Mean sea levels in the Tsushima Warm Current region shows the values of +5 to+10cm along the coast of Kyushu where the warm current starts from, +10 to+20cm along the Sanin district in the southwestern part of the Japan sea, +20 to+30cm along the coast of Hokuriku and the west coast of the Tohoku district, +15cm along the west coast of the Tohoku district, −15cm along the west coast of Hokkaido and +5 to+10cm along the coast of the Okhotsk sea where an extension of the Tsushima Warm Current—so-called Soya Warm Current—is flowing, while in the Pacific ocean the distribution shows the values of −10 to −5cm along the south coast of Japan

Fig. 4. Mean sea level in cm above T.P. from 1963 to 1968 and the pattern of the current system around Japan (the mean position of the axis of the Kuroshio was obtained by Watanabe, et al (1971)), 1; Soya warm current, 2; Tsugaru warm current, 3; Oyashio, a; Tsugaru straits, b; Soya straits, and c; Tsushima straits.

where the Kuroshio is flowing, +5 to+10cm along the coast of the Tohoku district east of which the Tsugaru Warm Current (another branch of the Tsushima Warm Current) flows southwards, and about +15cm along the southeast of Hokkaido where the coastal branch of the Oyashio is flowing (see fig. 4).

In the distributions of the seasonal sea level the same pattern can be seen. Speaking about the seasonal change, the highest value appears in summer and the lowest in winter. For example, at the northwestern coast of the Tohoku district the value reaches +44cm in summer and +25cm in winter, 1965 (see figs. 5 and 7).

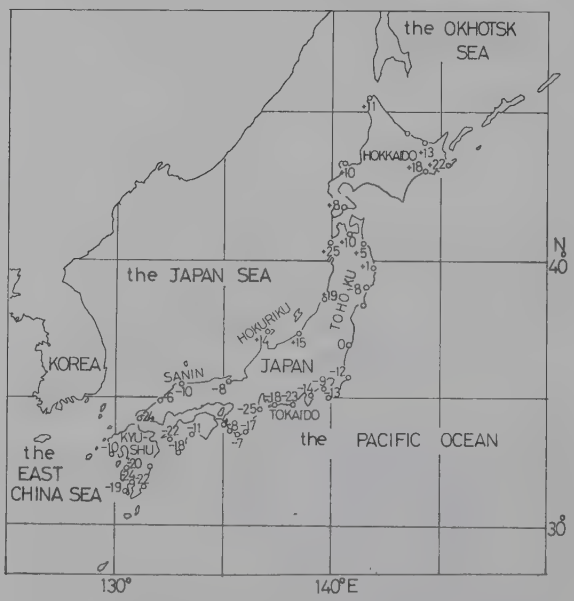

Fig. 5. Mean sea level in cm above. T.P. (winter, 1965).

3. Discussion

When the friction is not considered, the equations of motion for stationary state can be integrated to so-called Bernoulli's formura (for example, see FOFFONOF, 1954). Applying this to the Tsushima Warm Current, the current speeds in nearly equal to zero from the observed fact at the starting point corresponding to the

Fig. 6. Mean sea level in cm above T.P. and surface temperature in °C (spring, 1965).

just south of the Tsushima Straits, so the sea levels along the stream must be lower than those near the starting points when no energy is supplied. Even if the friction is considered, the situation can not be changed. In the Japan sea there are no external forces affecting the sea level change except NW monsoon blowing hard especially in the northern part in winter. In order to explain the fact that higher sea levels are observed in the down-stream of the Tsushima Warm Current, the following reasons are considered.

(1) The results of leveling used contains systematic errors, such as the level surface determined is not level, but lowers towards north.

(2) A time dependent explanation is neccessary (so Bernoulli's law can not hold); For example, blocks of warm water remaining in the subsequent seasons.

(3) Other mechanisms, such as acceleration of the current by the interaction between warm water and cold water, should be considered.

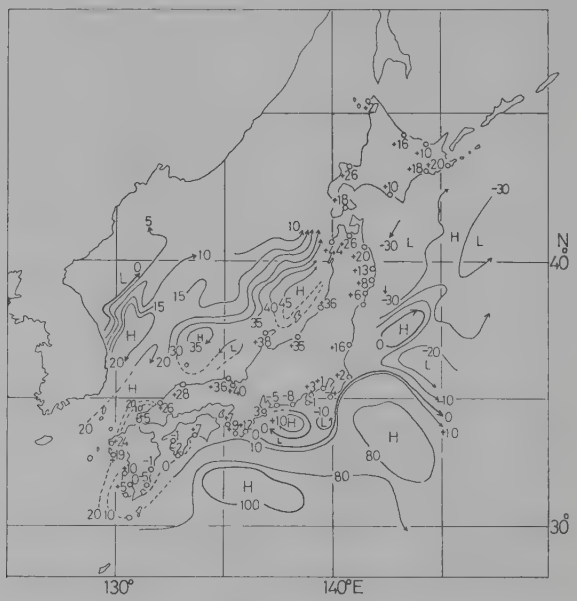

Fig. 7. Mean sea level in cm above T.P. and surface dynamic depth anomaly adjusted to it (above 1000db surface in the Pacific Ocean and 500db in the Japan sea) (summer, 1965).

The tendency of sea levels in the figures seems to become higher towards the northeastern part of the islands of Japan at first glance. This makes us suspect the systematic errors of the results of leveling. The tendency is, however, agree with the distribution of dynamic depth anomaly shown in figures 7 and 9, which is adjusted to the coastal values of sea level measured with tidal stations by the use of surface currents, density, temperature distributions, etc. between the coast and the nearest deep observation points. The distributions show the good agreement between coastal shape of sea level and that extrapolated from the results of oceanographic observations which are determined independently. The higher sea levels in the downstrem of the Tsushima Warm Current region should be treated as it is. The other explanations will be left in future researches.

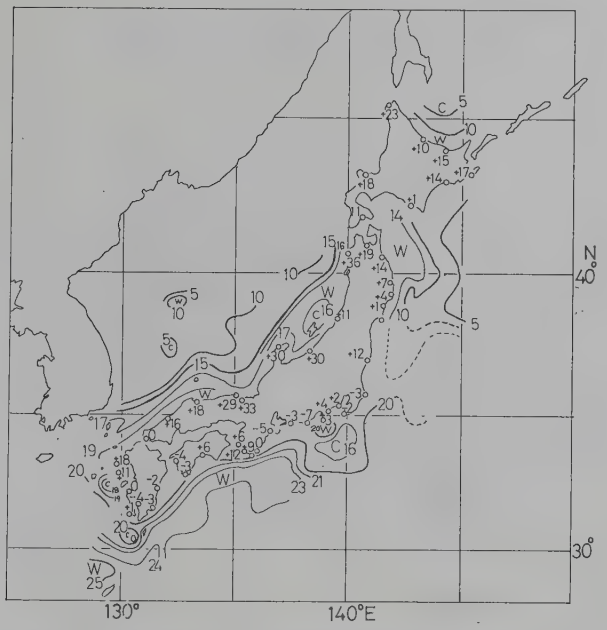

Fig. 8. Mean sea level in cm above T.P. and sea surface temperature in °C (autumn, 1965).

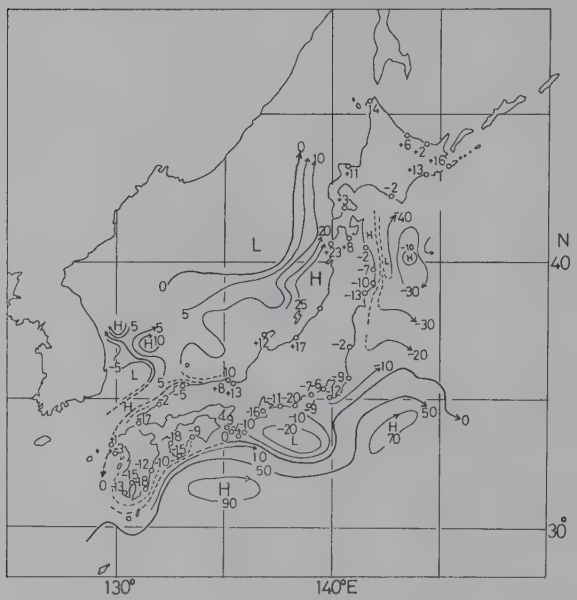

Fig. 9. Mean sea level in cm above T.P. and surface dynamic depth anomaly adjusted to it (above 1000db surface in the Pacific Ocean and 500db in the Japan sea) (winter, 1966).

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The author wishes to thank Dr. MIYAZAKI, Mr. URUNO and Mr. INOUE for their useful advice, and also Dr. MASUZAWA for his encouragement.

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H. Iida: The shape of the sea surface along the coast of Japan

日本海沿岸の海面の形について

飯　田　隼　人

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気象庁・海上保安庁・国土地理院などの全国の約40検潮所の資料をもとにして，一定基準面（TPを選んだ）上の水位分布を調べた．TP上の値に直すために1969年国土地理院公表の全国水準網の平均成果を用いた．これは1963～68年の比較的短期間に全国的な規模で密に行なわれたものである．それ以前の平均成果は範囲も狭く網も比較的粗であった．検潮所と一等水準面との間の取付測量業務が気象庁で確立したのもこの10年位のうちで，1969年以前の平均成果を使用して全国的な規模での沿岸の海面の形を求めることは出来なかった．平均水面の資料としては，1963～1968年の間の平均水面の値を，また，一年間の資料としては．上記期間の中間年1965年の月平均水位を使用した．平均水面分布をみると，期待されていたように，日本海側で高く，太平洋側で低くなっている．対馬暖流沿いの沿岸での水位は出発点の九州西岸では，＋5～＋10 cm で，そこから日本海沿岸沿いに水位が上昇して，青森県岩崎で最高に達した後は，じょじょに下りながら．オホーツク海に入り宗谷暖流となる．ここでの水位は ＋5～＋10 cm となっている．太平洋岸では黒潮流域は －1.5～－5 cm と低く，とくに東海道沿岸では低くなっている．津軽暖流の南下している三陸沿岸では＋5～＋10 cm と比較的高くなっている．（第4図参照）

以上の結果は，海洋観測結果による力学的高低分布と非常によい一致を示している．（第7および9図参照）

気象庁

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